Kinematics and Cloud to Cloud Abundance Ratios: A Rosetta Stone for Disk and Halo Components in Mg II Absorbers

Christopher W. Churchill and Jane C. Charlton

Pennsylvania State University, University Park,PA 16802

Abstract. Based upon QSO absorption line studies, galaxies at $0.3 \leq z \leq 1.0$ are seen to have extended gaseous "halos". When the absorption lines are observed at high resolution, the velocity distribution of the absorbing gas gives clues as to where this gas actually arises in and around the galaxies. Cloud to cloud abundance ratios provide further clues, given that the ionization conditions and chemical evolution histories of outer halos clouds, spiral disk clouds, and clouds in elliptical galaxies are different. The key to interpreting the high redshift data is the Milky Way galaxy, the absorption line "Rosetta stone".

1. Introduction

In this volume, Steidel has described observational evidence for extended gaseous "halos" surrounding normal L^* galaxies at $0.3 \leq z \leq 1.0$ (also see Steidel 1995), where the tracer for low ionization conditions is the strong resonant Mg II $\lambda\lambda 2976, 2803$ doublet. Mo has reviewed the properties of these halos from a theoretical view point (this volume). Here, we discuss methods for constraining the spatial distribution of the absorbing gas using high resolution data and models based upon known spatial distributions, kinematics, and chemical enrichment histories of galactic gas. Is there a relationship between the gas kinematics and the spatial locations/distributions of the absorbing gas that can be exploited to infer where in a galaxy absorbing gas arises? Is there a relationship between metal abundance patterns and cloud velocities that could be exploited to this end? It may be that, on a case–by–case basis, we can infer what parts of galaxies are giving rise to the absorbing gas. With a large enough sample we could then infer details about the evolution of galactic gas.

2. Observations and Models

We have observed the Mg II doublet and accompanying strong Fe II transitions with 6.6 km s^{-1} resolution using the HIRES on Keck (Churchill 1997; Churchill et al. 1997). We have observed ~ 30 galaxies in absorption at $0.4 \leq z \leq 1.0$. With HIRES (Vogt 1994), the absorbing gas is seen to resolve into multiple clouds, each having a well defined velocity, column density and broadening parameter. We constructed Monte Carlo model galaxies with disk–only (D), halo–only (H), and disk+halo (D+H) gas distributions. D components were given rotational kinematics and H components were given either infall or isotropic kinematics (cf. Charlton & Churchill 1996). Random "QSO sight lines" were then passed through the galaxies and synthetic HIRES absorp-

tion spectra were generated for the Mg II doublet and for several strong Fe II transitions. These "spectra" were analyzed using Voigt profile fitting in precisely the same fashion as the observational data. A small sample of model data and the HIRES data are shown in Fig. 1 for the Mg II $\lambda 2796$ transition. Ticks mark each cloud's velocity.

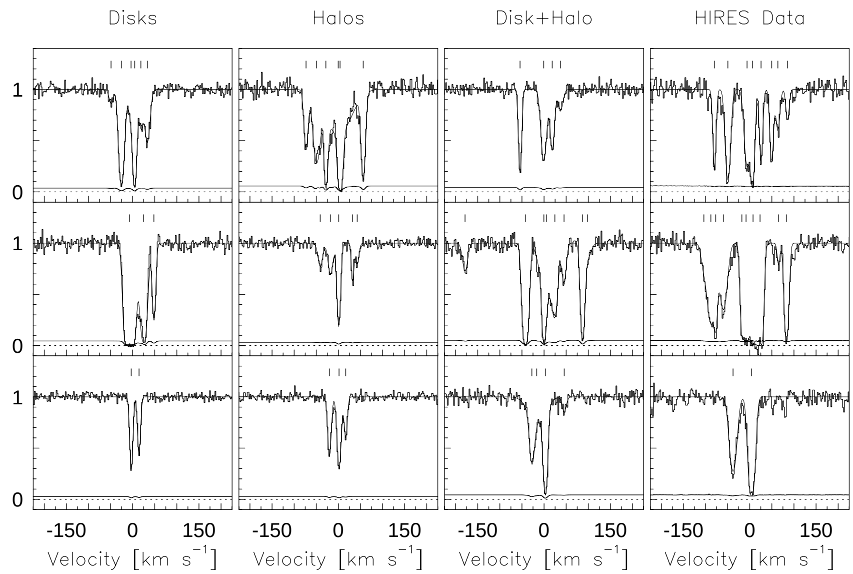

Figure 1. Small sample of model HIRES spectra of the Mg II $\lambda 2796$ transition for disk, halo, and disk+halo models. The right most panel shows a sample of observed spectra (see text for discussion).

3. Modeling Galaxy Gas Kinematics

As seen in Fig. 1, the number of clouds and the cloud velocities and column densities vary from galaxy to galaxy. However, in the majority of the galaxies, the gas velocity distribution suggests a single, dominant absorbing "complex" around which smaller clouds are clustered. "High velocity" ($v \geq 40$ km s^{-1}) clouds are characterized by equivalent widths less than 0.1 Å and velocity widths less than 10 km s^{-1}; they are relatively small or low density. In the final analysis (Charlton & Churchill 1997), the models that provide the best statistical match to the data include both the D and H components, either as a single population of D+H absorbers or a combined population of D–only and H–only absorbers. *Some* Mg II *absorbing gas is arising in spiral disks.*

4. Breaking the Disk/Halo Degeneracy

The difficulty of identifying which absorption lines arise in D or H components of galaxies is illustrated in the left hand panels of Fig. 2. Is there a technique that can be exploited so that one could securely infer which clouds arise in D or H components? Fitzpatrick & Spitzer (1994) have demonstrated that absorption properties of H I and H II regions, and of diffuse gas can be discerned by comparing the abundance ratios and ionization conditions on a cloud–by–cloud basis in high resolution spectra. As

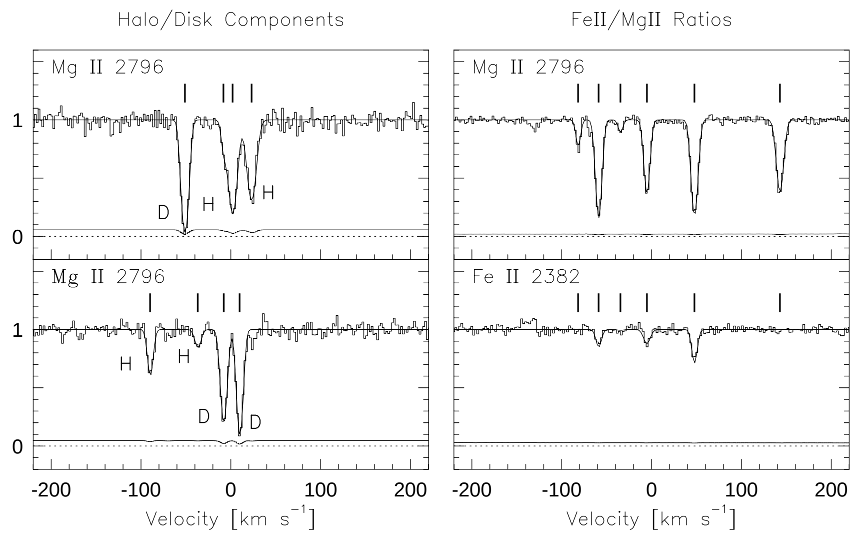

Figure 2. (left) Models of HIRES spectra with disk (D) and halo (H) clouds labeled. Zero velocity is given by the optical depth mean. (right) Observed HIRES Mg II and Fe II profiles at $z = 1.32$ showing the variation in the ratio on a cloud by cloud basis (see text for discussion).

illustrated in the right hand panels of Fig. 2, the column density ratios of Fe II to Mg II are seen to vary from cloud to cloud, sometimes by a factor of 10 (compare the $v \sim 0$ and 140 km s^{-1} clouds). This ratio is sensitive to the chemical enrichment history of the particular gas cloud, its ionization condition, and its depletion pattern. In the Galaxy, these conditions are seen to be more–less unique depending upon if they are cool–disk, warm–disk, or halo clouds (Savage & Sembach 1996). It appears that with the Galactic "Rosetta stone", a deeper understanding of high redshift galactic gas is forthcoming.

Acknowledgments. CWC thanks the LOC for partial financial support to attend this Workshop. This work is supported in part by NSF grant AST–9617185.

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